

## **Alternative Penetrometers to Measure the Near Surface Strength of Soft Seafloor Soils**

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### **LONG-TERM GOALS**

Develop an alternative penetrometer to accurately measure the undrained shear strength of near surface soft seafloor soils. Further the education of participating undergraduate students by active involvement in research and mentoring activities.

### **OBJECTIVES**

In collaboration with the Naval Facilities Engineering Service Center (NFESC) in Port Hueneme, assess the feasibility of using full-flow penetrometer technology to meet Navy requirements. Design, build, and test a full-flow penetrometer that will accurately measure the near surface shear strength of soft seafloor soils.

### **APPROACH**

*Review current full-flow penetrometer technology:*

Review technical literature to evaluate the state-of-the-art in full-flow penetrometer technology. Discuss with end users and manufacturers the state-of-practice of full-flow penetrometers in scientific and engineering practice. Identify unresolved issues of flow-penetrometer technology and how they can be met to meet the needs of the Navy.

*Probe design and construction:*

Select probe type and size for design and construction. The probe will be designed to be compatible with the Navy's seabed cone penetrometer unit. The probe will be outfitted with load cells to measure penetration resistance, sleeve friction, and a pressure transducer to measure porewater pressures. Nearly all full-flow penetrometers in use today are either spherical (ball) or cylindrical (t-bar). The features and characteristics most critical to the needs of the Navy will dictate the selection of the probe type.

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### *Laboratory Probe Calibration:*

All penetrometers rely on calibration to determine a probe factor that is used in the determination of the field undrained shear strength. Calibration is especially important for new types of probes such as the full-flow penetrometer where data and experience is limited. Calibration will be performed in the laboratory by pushing the full-flow penetrometer into prepared large-scale Kaolin specimens of known strength and comparing the measured resistance with the specimen's undrained shear strength. The ratio of these quantities is the experimentally determined laboratory probe factor. Adjacent cone penetrometer and vane shear tests will also be performed in the specimens to allow side-by-side comparisons and evaluation of the penetration resistance and shear strength with depth; and to establish a baseline to assess the improvement in shear strength accuracy for the full-flow penetrometer. Also, undisturbed samples will be taken from the Kaolin specimens and tested by consolidated undrained triaxial compression tests and by direct simple shear tests.

### *Probe Validation through Field Trials:*

The final phase of the project involves field testing at onshore sites to validate the recommended probe factors against real soils. The probe factors from the field trials will be calculated and compared with the theoretical and laboratory determined values. Ultimately, the potential of the full-flow penetrometer to more accurately determine the shear strength of soft soils (compared to the CPT and Vane Shear) will be evaluated. Parallel CPTs and vane shear tests will also be performed to allow side-by-side comparison and evaluation of the penetration resistance and shear strength with depth; and to establish a baseline to assess the improvement in shear strength accuracy for the full-flow penetrometer. High quality undisturbed clay samples will be obtained for laboratory strength testing (triaxial and simple shear).

### *Educational Program:*

One of the main objectives of this project is to actively involve undergraduate students in the research effort and to provide mentorship. The project will involve three undergraduate civil engineering students in research and mentoring activities throughout the duration of the project. The mentoring activities are designed to provide the students with opportunities to interact with navy engineers professionally and socially.

## **WORK COMPLETED**

Review of current flow penetrometer technology has been completed and discussions with end users and manufacturers of flow penetrometers were accomplished. A spherical ball penetrometer was selected for design and construction. The ball has an area ten times that of the standard cone penetrometer ( $100 \text{ cm}^2$  compared to  $10 \text{ cm}^2$ ) to ensure good resolution of measured resistances in soft soils and to be consistent with published standards. The ball was designed to be interchangeable with the conical cone tip so that the same sensors and load cells embedded in the cone mandrel could be used with both the ball and cone. A vane shear device was also purchased. Figure 1 shows a photograph of the penetrometers purchased for this project.

A specially designed consolidation tank was built to create the large-scale clay specimens needed for the laboratory probe calibration (see Figure 2). The tank is 42 inches in diameter and 72 inches in height. It contains a fitted and honed main hydraulic piston that is actuated by a hydraulic pump driven

by an air-cooled electric motor. Clay specimens are created by placing Kaolin slurry into the tank and compressing the slurry using the tank's main hydraulic piston. Consolidation takes place as the water is expelled through drainage lines on the top and bottom of the tank through a specially designed filtration system that allows water to drain but leaves the Kaolin behind. Digital readouts display applied pressure and displacement of the piston during consolidation of the clay specimen. Once consolidation is complete, the hydraulic piston is removed and a tooling plate is attached and actuated by a pair of auxiliary pistons attached to the tank. The tooling plate allows the different probes to be advanced into the clay cake at uniform and controllable penetration rates. Data acquisition systems for the cone, ball penetrometer, and vane collect readings of resistance which then can be converted to strength for comparison purposes.

Three undergraduate freshmen and one graduate student were selected for the project and are working with the PI. The graduate student is primarily involved with the triaxial and simple shear testing of the Kaolin specimens while the undergraduate students are involved in all aspects of the project. The students have also been participants at several meetings with engineers from NFESC.

In January, a special presentation of the project and test results was presented to Vice Adm. Kevin McCoy, Commander of NAVSEA, at the NAVSEA Hispanic Owned Small Business Conference at California State University, Los Angeles.

## **RESULTS**

A significant technical challenge in this project was the design and construction of the consolidation tank to facilitate creation of the large-scale clay specimens. Testing of large-scale clay specimens at this size (42 inches in diameter and 72 inches in height) is rarely undertaken due to the complexity of the equipment needed. However, the payoff is the ability to test the probes on soil specimens at field scale rather than on soil specimens at a reduced model scale. This eliminates the need to compensate for any possible scale effects. The design of the tank began in October 2008 and final construction was completed in August 2009. A completely unique and one-of-a-kind consolidation tank has been built as shown on Figure 2. Preliminary tests with a full load of slurry in the tank have shown that the system consolidates the slurry efficiently and effectively by expelling water through the filtration system. Final hookups are being implemented and production testing will begin in about a month with the primary research data forthcoming.

The ability to create large-scale clay specimens is a unique capability and provides for many future testing possibilities of interest to the Navy. Large-scale clay specimens created using the consolidation tank may be used to test a variety of probes, penetrometers, foundations and anchors. Also, the laboratory direct simple shear and triaxial devices purchased as part of this project could also be used in support of ONR's other research initiatives such as the Tidal Flats DRI.

## **IMPACT/APPLICATIONS**

The impact of the research is to increase the technical capabilities of the Navy by developing a tool to measure the strength of soft seafloor soils. Results of this research will provide immediate and practical information for use by Navy commands. The project will also further the education of undergraduate and graduate students by active involvement in research and mentoring activities. It will expose the students to research projects important to the mission of the Navy with the intent that they may consider naval careers

## RELATED PROJECTS

None



*Figure 1: Photograph of vane device, cone penetrometer, and spherical ball penetrometer used in the investigation.*



***Figure 2: Photograph of custom-designed and built consolidation tank for creating large-scale clay specimens. Note main hydraulic piston to the left of the tank.***